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SIMULATION BASED R&D FOR SPACE VEHICLE CONCEPTS

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THIS IS A SMALL BUSINESS INNOVATION RESEARCH (SBIR) PHASE 1 REPORT

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13. ABSTRACT *(Maximum 200 Words)*

Report developed under SBIR contract for topic AF00-277. The primary objective of this Phase 1 effort was to demonstrate the feasibility of integrating a set of simulation based design and performance evaluation tools linked through a generalized, common database system that supports rapid assessment of space vehicle concepts. An end-to-end, simulation based development approach, featuring rapid prototyping and integrated development tools, can enable a small team of engineers to evaluate space vehicle concepts, support development, and validate performance for space vehicles. This set of tools can range from simplified concept definition and assessment tools to non-real time and real time high fidelity simulations. This effort has focused on demonstrating how the integration of a subset of tools can support rapid design and performance assessments of reusable launch vehicles. Analytical tools considered in this Phase included a vehicle sizing tool, several trajectory design applications with various levels of guidance optimization and hi-fidelity 6 Degree of Freedom (6DOF) simulation environment. These tools have been integrated with an open architecture common database system, utilizing our Integrated Development & Operations (IDO) process. The IDO process directly supports all system life cycle phases, starting with conceptual design, and evolving through preliminary design, detailed design, and finally operations of space vehicle system. This effort focused on implementation of the Integrated Database System (IDS), and application interfaces to a selected subset of these Phase 1 design tools, utilizing a generic RLV system design to demonstrate the benefits of data capture, configuration control and consistency across all tools under study. These three elements (simulation based R&D tools the IDS, and the IDO process) comprise what USL calls the Integrated Development and Operations System (IDOS). The project culminated in an on-site feasibility demonstration and briefing (11/3/00).

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I. Phase I Project Objectives

A. Introduction

The primary objective of the Universal Space Lines Phase I effort was to demonstrate the feasibility of integrating a set of simulation based design and performance evaluation tools linked through a generalized, common database system that supports rapid assessment of space vehicle concepts. An end-to-end, simulation based development approach, featuring rapid prototyping and integrated development tools, can enable a small team of engineers to evaluate space vehicle concepts, support development, and validate performance for space vehicles. This set of tools can range from simplified concept definition and assessment tools to non-real time and real time high fidelity simulations. Our Phase I effort has focused on demonstrating how the integration of a subset of tools can support rapid design and performance assessments of reusable launch vehicles. Analytical tools considered in this Phase included a vehicle sizing tool, several trajectory design applications with various levels of guidance optimization and a hi-fidelity 6 Degree of Freedom (6DOF) simulation environment. These tools have been integrated with an open architecture common database system, utilizing our Integrated Development & Operations (IDO) process. The IDO process directly supports all system life cycle phases, starting with conceptual design, and evolving through preliminary design, detailed design, and finally operations of a space vehicle system. This effort focused on implementation of the Integrated Database System (IDS), and application interfaces to a selected subset of these Phase I design tools, utilizing a generic RLV system design to demonstrate the benefits of data capture, configuration control and consistency across all tools under study. These three elements (simulation based R&D tools, the IDS, and the IDO process) comprise what USL calls the Integrated Development and Operations System (IDOS). The project culminated in an on-site (Air Force Research Laboratory/Wright-Patterson AFB) feasibility demonstration and briefing.

II. Phase I Work Summary

A. Work Plan Description and Status

Early efforts during the project concentrated on defining the Integrated Database System (IDS) requirements and developing initial 3 DOF and 6 DOF simulation tools for a reusable launch vehicle that represents a "generic" RLV system. The Space Clipper (SC) Single Stage to Orbit (SSTO) generic configuration was chosen as the RLV system to be used for validation and demonstration purposes. We designated this RLV system SOV-X. Design and performance data associated with this system were used to implement and test prototypes of the IDS and simulation based R&D tools as part of this Phase I concept feasibility demonstration. The baselined IDS architecture and database design considered for this effort is defined in Figure 1.

In order to assure consistency between AFRL, Air Vehicle Directorate (VA), Control Sciences Division (VAC) and branch department needs, with our Phase I IDS and application interface focus, a kickoff meeting was held on 6/8/00 with the VAC division at WPAFB. An internal kickoff meeting was held 6/9/00 with USL and consultant team members to ensure tasks focused on the needs identified by our customer at the on-site meeting.

We used these kickoff meetings to confirm the project requirements, approach and Statements Of Work (SOW) with our VAC customer. During our on-site visit we discussed the project with key technical personnel, to better understand their requirements and needs.

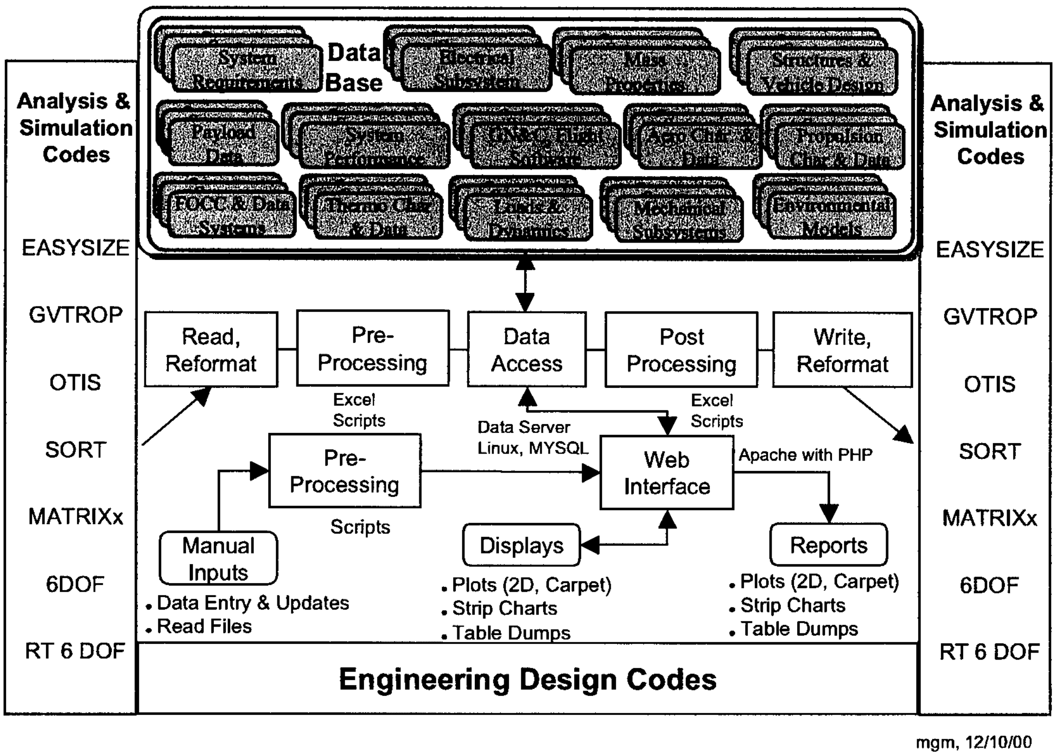


Figure 1 - IDS Architecture was defined early in project

Utilizing the SOV-X, with its relatively mature design database, as a point of departure our 3 DOF and MatrixX 6 DOF simulations were validated early in the project schedule. IDS requirements and baseline architecture were also established at this point and are documented graphically in Figure 1.

SOV-X specific data was input into our EasySize preliminary sizing tool, and outputs were used to support initial development of PHP scripts that provide the mechanisms for data interfacing to the IDS. PHP, originally called "Personal Home Page Tools", is a language for creating interactive web sites and is used on over 3 million web sites around the world.

Updates and modifications were made to both GVTROP and OTIS, trajectory optimization tools to support the SOV-X configuration. Significant code modifications to GVTROP were implemented to incorporate inertial Euler angle guidance typically used for rocket launch vehicle trajectory simulation – previously GVTROP guidance options involved only relative state variables, typically used for aerospace plane vehicle trajectory simulation. OTIS already had inertial Euler angle guidance capability. In addition another 3 DOF simulation, "Simulation and Optimization of Rocket Trajectories" or SORT, was included in the toolset interface to IDS. SORT simulation analysis efforts were initially performed under a NASA SBIR (Launch Vehicle Integrated Guidance Software – Reducing Operations Cost, NASA SBIR 99 Phase 1, Contract Number NAS8-00071). SORT analysis served as a check case for the GVTROP and OTIS simulations, adding value to this SBIR by providing another generic 3 DOF tool interface to the IDS. This code is driven by an "input deck" that the analysis modifies. A generic input deck has been created with each input identified and linked to the IDS core data.

Modifications were made to an existing MatrixX 6 DOF to reflect a SOV-X design configuration. "Hard coded" data values were replaced with a structure that supports updates via the IDS. This modified version of the 6DOF accepts an "input file" that resembles an array of all the data inputs including all aero coefficients, mass properties, subsystem, environment models and state initialization values. Models have been modularized to enable a more generic 6DOF application. Interface Control Documents (ICDs) were developed to define these data interfaces.

The SOV-X 6 DOF simulation database was used to prototype and populate the IDS and validate interfaces since the 6 DOF is more complex than the 3 DOF's.

Using the initial requirements definition, Integrated Database System (IDS) development evolved in three areas; (1) general IDS design along with its Web Interface, (2) IDS data layout and definition of the "core data" to be stored and the derived parameters and their algorithmic relationships required for generating the IDS reports (using PHP scripts), and (3) the detailed definition of IDS reports to be generated to support data browsing, building input data files for engineering design codes and simulations, and for building "mission constant" data files. These three areas are detailed in Figure 2 along with ground rules that define the attributes of the stored "core data". Common data that is shared between design/simulation codes in the key areas of mass properties, aerodynamics and propulsion characteristics were defined, developed and implemented within a common pre-defined data structure and format consistent with our IDS.

Core Data Ground Rules

ejr, 8/17/00

- **Core Data is: Data that is required to directly Design, Validate, or Deliver an RLV System that meets the Performance Requirements - SBIR emphasis is on "Soft Products"**
- **The IDS supports simulations and design codes - not vice-versa. For Phase I, a finite number of simulations & codes are defined.**
- **If data is needed to generate a "Report", it is considered "Core Data"**
- **Core Data is stored only once - all other data is either derived or a result of a simulation or design code execution**

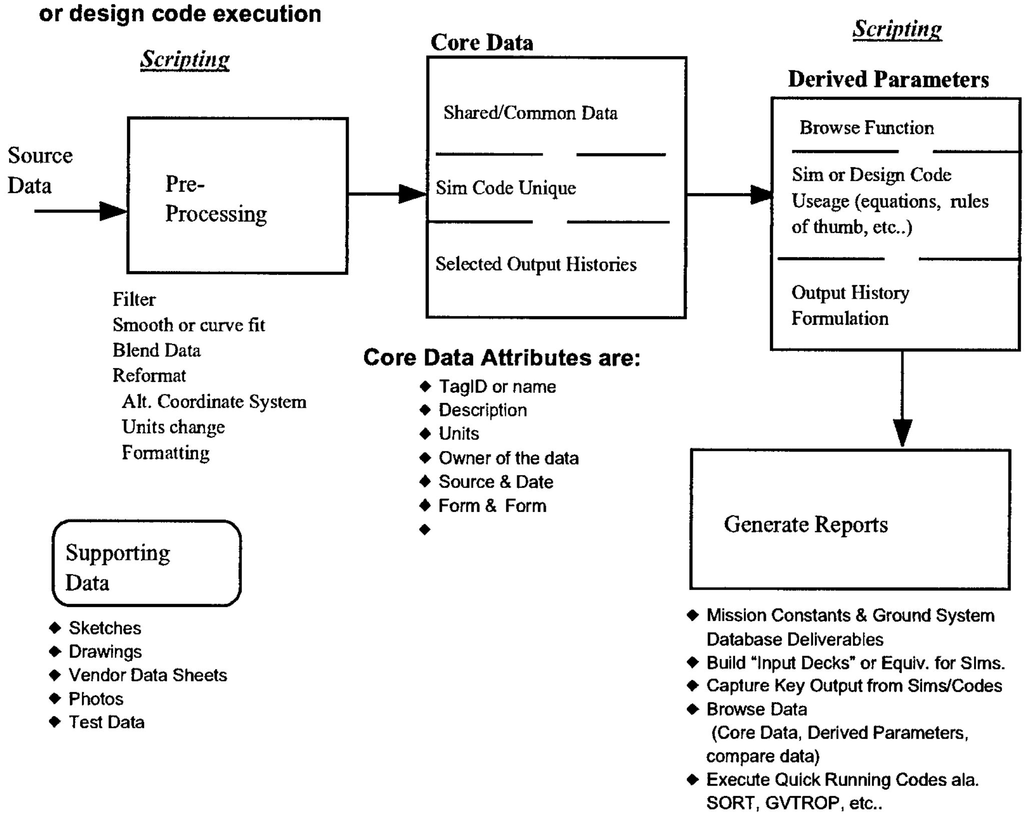


Figure 2 – IDS Data Flows and Interface Processing are well defined

A set of incremental development products and mini-demos were defined to incrementally demonstrate the overall feasibility of the IDS approach consistent with our proposed Simulation Based R&D process and tools. These incremental mini-demos naturally evolved into the end-to-end feasibility demonstration and briefing of the integrated IDS system provided to our AF customer on 11/3/00 at AFRL/WPAFB.

The IDS data server is a Linux based web server with a back-end SQL data server system (see Figure 3). The open source Linux operating system was chosen because of the stability required to host the database and to mitigate technology upgrade risks associated with closed source operating systems. The web server chosen is the industry's standard web server, **Apache**. Apache has been the most popular web server on the Internet since April of 1996. The March 2000 Netcraft Web Server Survey found that over 60% of the web sites on the Internet are using Apache (over 62% if Apache derivatives are included), thus making it more widely used than all other web servers combined.

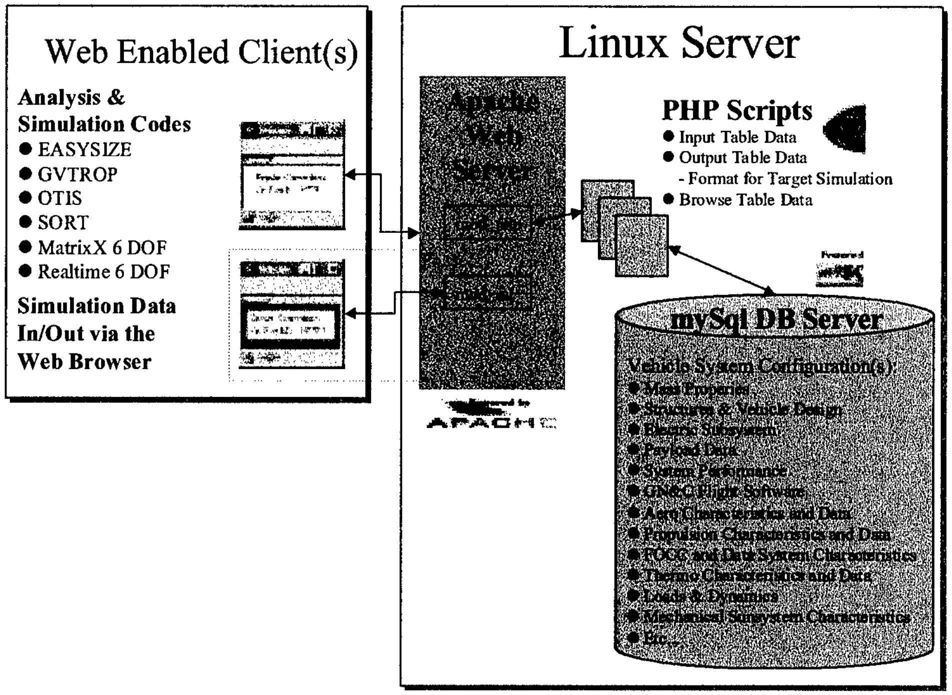


Figure 3 – Our Web-based IDS system represents a low-cost, highly flexible implementation

More information on this server application can be found at http://www.apache.org. The back-end database chosen is another industry standard, **MySQL**, known for it's stability and speed, both of which were required for the IDS. Both MySQL and Apache are open source applications. Additional information on this application can be located at http://www.MySQL.com. In order to manage data interfaces to the MySQL database, we used the PHP script language. PHP is a widely used open source general-purpose scripting language that is especially suited for Web development and can be embedded into HTML. Its syntax draws upon C, Java, and Perl, and is easy to learn. PHP executes on many different platforms and can be used as a standalone executable or as a module under a variety of Web servers. It has excellent support for commercial databases, XML, LDAP, IMAP, Java, various Internet protocols, and general data manipulation, and is accessible via its powerful API. It is actively developed and supported by a talented and energetic international team. Numerous open source and commercial PHP-based application packages are available. Currently, these packages are installed and running on our IDS PC based Linux server platform in the Colorado office. The system is available for review online at http://198.173.155.76/ids/index.php.

A Web based plotting and trending tool, Web Interactive Graphics or WIG (Utilizing PGPLOT Library), was integrated into the IDS for easily viewing and comparing engineering data and for comparison of performance results from the 3 DOF and 6 DOF simulations. This command driven plotting tool is capable of reading ASCII files and over plotting of engineering data. This key data visualization tool enables an end user to easily view and print data plots over the Web from an engineer's common work environment and format it for X-Windows, Postscript or Tektronics.

During Phase I, progress was made in defining the actual data that will be held in the database. The common data among applications and tools was refined into what the "Core Data" should be for a given vehicle configuration and attention was focused on how it should be represented in the database itself. This was a critical step because the representation of the data interface to all the input and output routines needs to be consistent. The data is organized into logical categories as shown in the database block in Figure 1 (which represented our point of departure for data organization), and a specific vehicle configuration represents the top-level configuration item for that data. This configuration item then holds all the various logical categories of data that define the configuration. The IDS is designed to manage all the data for various vehicles and even many versions of the same vehicle, i.e. vehicle configurations. Progress was made in gathering all of the engineering design code and simulation data for this Phase I SBIR that can be input into the database in a uniform generic fashion. Once that data is stored in the database, tailored reports are generated in various formats for each simulation client. These IDS report formats and parameters derived from the core data for use in the engineering design codes and simulations were further defined and documented through Interface Control Documents (ICDs) for each of the tools being considered for this Phase I SBIR. Working examples of these ICDs are integrated online into the IDS.

III. Phase I Results

The Phase I results demonstrate that the IDOS approach to the development of Simulation Based R&D tools is feasible. The Phase I IDOS simulation tools were incrementally developed and tested along with the incremental development and test of the Integrated Database System (IDS). A series of 47 incremental development steps and tests were completed during the Phase I program leading up to a fully integrated test of the end-to-end IDOS system.

The feasibility of the IDOS was demonstrated through extensive testing of each major element leading to an overall integrated system test and demonstration. This end-to-end system demonstration has been completed at the USL development facility in Colorado. All Phase I objectives were met and exceeded. An onsite demonstration and final briefing of the IDOS prototype was also provided for the VAC division on November 3, 2000 at WPAFB.

The IDOS capabilities that were developed and demonstrated are evidence that the Phase I objectives were met. These capabilities and features are summarized in Table 1. Our accomplishments during Phase I provide a solid foundation for the Phase II project where these prototypes are carried forward and evolved into commercial products.

Table 1 Demonstrated Phase I Capabilities of IDOS

Tool	*Description*	*Demonstrated Capabilities*	*Verification Test*
Integrated Database System (IDS)	Linux Based Data server & software that manages core data and interfaces via Web to Simulation Based R&D tools	Core Engr data stored one time P.C. based server Linux Operating System &development environment Uses Apache PHP, MYSQL User access via Web Interface Flexible interfaces that can tailor reports Manage multiple configurations On-Line Documentation System Host to selected Design & Simulation codes Real Time Data Management System Web Interface Graphics & Displays Able to Query, change, plot, overlay data Supports data trending & IVHM processing	I-1,2,3,4, 5,6,7
EASYSIZE	Conceptual Design tool using Excel Spreadsheet	Vehicle Sizing tool - parametric Level 0 design assessment Interfaces to IDS Runs on IDS server or remote Easy to Modify and maintain Demonstrated for SOV-X configuration	E-1,2,3,4 5,6
SORT	3 DOF Trajectory Simulation	Optimize rocket trajectories Runs Fast Interfaces to IDS Runs on IDS server or remote Supports quick turnaround mission development Demonstrated for SOV-X config & changes Generates 6 DOF command profiles Results validated with GVTROP, OTIS, 6 DOF	S-1,2,3
GVTROP	3 DOF Trajectory Simulation	Easy to Use & modify, Intuitive, Runs Fast Guidance & Propulsion models Optimization with constraints Interfaces to IDS Runs on IDS server or remote Supports quick turnaround mission development Demonstrated for SOV-X config & changes Generates 6 DOF command profiles Results validated with SORT, OTIS, 6 DOF	G-1,2,3
OTIS	3 DOF Trajectory Simulation	Uses Implicit Simulation method Solves complex trajectory with multiple, varying constraints Runs remote on Users platform Demonstrated for SOV-X config & changes Generates 6 DOF command profiles Results validated with GVTROP, SORT, 6 DOF	O-1,2,3

Table 1 Demonstrated Phase I Capabilities of IDOS

Table 1 Demonstrated Phase I Capabilities of IDOS (Cont'd)			
Tool	***Description***	***Demonstrated Capabilities***	***Verification Test***
MatrixX 6 DOF RLV Simulation	Hi-Fidelity Six Degree of Freedom, Vehicle Simulation	Graphical programming Linear & Non-linear modeling Object Oriented, COTS tool Supports autocoding & real time Generates a generic 6 DOF that can run anywhere Hi-Fidelity RLV models Highly reusable models & simulations Interfaces to IDS Runs on IDS server or remote Supports quick turnaround mission development Demonstrated for SOV-X config & changes Results validated with SORT, OTIS, GVTROP	M-1,2,3
MatrixX Real Time 6 DOF RLV Simulation	Hi-Fidelity real-time Six Degree of Freedom, Vehicle Simulation,	Supports real-time execution for HILS & MILS Generates Flight Software	R-1,2,3,4,5
End-to-End IDS System Demonstration			F-1,2,3,4
RaPIDS	Rapid Prototyping and Integrated Development System	Integrated design process 100% reuse of models & sims. Seamless transition to real time	All tests

Table 1 - Demonstrated Phase I Capabilities of IDOS

A summary of the incremental tests performed to demonstrate the capability of IDOS is shown in Table 2 including a brief description of each test and the date that the initial operating capability (IOC) of that functional module was achieved. With each incremental step and test, concept feasibility was validated, user feedback was obtained and the design altered so that the best features were implemented in the final incremental products. For example, the IDS to 3 DOF and 6 DOF simulation code interfaces were defined and adjusted as the tools evolved in their maturity.

#	Element Test I.D.	% Compl.	IOC	Description	Status
	EASYSIZE & Design Code Emulators				
1	E-1	100	15-Sep	*EASYSIZE Stand Alone*	Test Completed, Operation verified
2	E-2	100	9-Oct	*EASYSIZE with IDS*	Test Completed, Operation verified
3	E-3	100	6-Oct	*Populate Design Code Emulator(DCE) db*	Test Completed, Operation verified
4	E-4	100	6-Oct	*Exercise Design Code Emulator(DCE) db*	Test Completed, Operation verified
5	E-5	100	25-Oct	EASYSIZE=>DCE via IDS & Demo Scenarios	Test Completed, Operation verified
6	E-6	100	10-Oct	*EASYSIZE=>DCE via IDS & Web Interface*	Test Completed, Operation verified
					Test Completed, Operation verified
	IDS				Test Completed, Operation verified
7	I-1	100	1-Sep	*Define reqmts & Architect database System*	Test Completed, Operation verified
8	I-2	100	15. Oct	*Design & Demo generic IDS Web Interface for IDS*	Test Completed, Operation verified
9	I-3	100	24. Sep	*Demo Storage and Retrieval with Database Engine*	Test Completed, Operation verified
10	I-4	100	20. Oct	*Design & Demo Web based Pre-processors*	Test Completed, Operation verified
11	I-4a	100	24-Oct	*6 DOF, ref. M-3*	Test Completed, Operation verified
12	I-4b	100	14-Oct	*SORT, ref. S-3*	Test Completed, Operation verified
13	I-4c	100	9-Oct	*EASYSIZE, ref. E-3,4*	Test Completed, Operation verified
14	I-4e	100	8-Oct	*Design Code Emulator, ref. E-3,4*	Test Completed, Operation verified
15	I-4f	100	20-Oct	*GVTROP, ref. G-3*	Test Completed, Operation verified
16	I-4g	100	21-Oct	*OTIS, ref. O-3*	Test Completed, Operation verified
17	I-5			Populate & Demo the IDS System for	Test Completed, Operation verified
18	I-5a	100	25-Oct	*6 DOF, ref. M-3*	Test Completed, Operation verified
19	I-5b	100	15-Oct	*SORT, ref. S-3*	Test Completed, Operation verified
20	I-5c	100	9-Oct	*EASYSIZE, ref. E-3,4*	Test Completed, Operation verified
21	I-5e	100	8-Oct	*Design Code Emulator, ref. E-3,4*	Test Completed, Operation verified
22	I-5f	100	20-Oct	*GVTROP, ref. G-3*	Test Completed, Operation verified
23	I-5g	100	21-Oct	*OTIS, ref. O-3*	Test Completed, Operation verified
24	I-6	100	13-Oct	*Design & Demo data review, plotting, & display via Web*	Test Completed, Operation verified
25	I-7	100	27-Oct	*End-to-End Demo for SOV-X, ref. F-1*	Test Completed, Operation verified
	SORT				Test Completed, Operation verified
26	S-1	100	15-Sep	*SORT Standalone for SOV-X*	Test Completed, Operation verified
27	S-2	100	13-Oct	*Exercise SORT 3 DOF with IDS for SOV-X*	Test Completed, Operation verified
28	S-3	100	25-Oct	*Exercise SORT 3 DOF with IDS for SOV-X via Web*	Test Completed, Operation verified
	GVTROP				Test Completed, Operation verified
30	G-1	100	28-Sep	*GVTROP Standalone for SOV-X*	Test Completed, Operation verified
31	G-2	100	16-Oct	*Exercise GVTROP 3 DOF with IDS for SOV-X*	Test Completed, Operation verified
32	G-3	80	26-Oct	*Exercise GVTROP 3 DOF with IDS for SOV-X via Web*	Test 80%Completed, Operation verified
	OTIS				Test Completed, Operation verified
33	O-1	100	1-Oct	*OTIS Standalone for SOV-X*	Test Completed, Operation verified
34	O-2	100	14-Oct	*Exercise OTIS 3 DOF with IDS for SOV-X*	Test Completed, Operation verified
35	O-3	70	26-Oct	*Exercise OTIS 3 DOF with IDS for SOV-X via Web*	Test 70%Completed, Operation verified
	MATRIXx 6 DOF				Test Completed, Operation verified
36	M-1	100	1-Sep	*MATRIXx 6 DOF Standalone for SOV-X*	Test Completed, Operation verified
37	M-2	100	16-Oct	*Exercise MATRIXx 6 DOF with IDS for SOV-X*	Test Completed, Operation verified
38	M-3	100	26-Oct	*Exercise MATRIXx 6 DOF with IDS for SOV-X via Web*	Test Completed, Operation verified
	Real Time 6 DOF				Test Completed, Operation verified
39	RT-1	100	1-Sep	*Linux Operational on IDS Server (PC Platform)*	Test Completed, Operation verified
40	RT-2	100	6-Oct	*RT Linux Operational on IDS Server (PC Platform)*	Test Completed, Operation verified
41	RT-3	100	29-Sep	*Autocoded RLV System Simulation, Standalone for SOV-X*	Test Completed, Operation verified
42	RT-4	100	15-Oct	Exercise Autocoded RLV System Simulation with IDS	Test Completed, Operation verified
43	RT-5	100	25-Oct	Exercise Autocoded RLV System Simulation with IDS via Web	Test Completed, Operation verified
	Integrated System				
44	F-1	100	6-Oct	*Exercise EASYSIZE=>DCE with IDS via Web, ref. E-6*	Test Completed, Operation verified
45	F-2	100	13-Oct	*Exercise EZ=>DCE=>SORT with IDS via Web, ref. S-3*	Test Completed, Operation verified
46	F-3	100	27-Oct	*Exercise EZ=>DCE=>SORT=>6DOF with IDS via Web, ref. M-3*	Test Completed, Operation verified
47	F-4	85	27-Oct	*Exercise RLV System Simulation with IDS for SOV-X, ref. F-3*	Test 85% Completed, Operation verified

Table 2 IDOS Tools and IDS Interfaces are Verified by Test

In addition to testing the tools, a set of IDOS test conditions implementing typical vehicle design change scenarios were incorporated into the test suites to assure that the tools were exercised to demonstrate that different space vehicles or modifications to them could be rapidly assessed. A summary of these vehicle and mission design change scenarios is

Summary IDS Demo Scenarios for Vehicle Changes				Updated 10/24/00,ejr
	Change Scenario	**Impact**	**Codes Effected**	**Comments**
1	Payload Mass +/- 10 %	Resizes vehicle length, changes mass prop.	EASYSIZE, DCE, SORT, 6 DOF, GVTROP, OTIS	Evalute design and performance impact of alternate payloads or sizing for growth capability
2	Payload Volume (e.g. Diameter +/- 5 %)	Resizes vehicle dia, changes mass prop., changes Ref Area	EASYSIZE, DCE, SORT, 6 DOF, GVTROP, OTIS	Effects the Aero scaling but not tables
3	Change ME ISP (+/- 5 %) Payload sensitivity to Orbit Sensitivity to ISP	No vehicle redesign, changes mass prop. & engine parameter	DCE, SORT, 6 DOF, GVTROP. OTIS	Start at SORT, Keep same basic design (no EASYSIZE), Keep same basic engine, evaluate performance sensitivity
4	Change Engines	Go from Ideal engine to J2 engine, must store alternate eng data	EASYSIZE, DCE, SORT, 6 DOF, GVTROP, OTIS	Keep LOX/LH2, alters # engines, thrust, ISP
5	Change Constraints	(+/- axial and/or lateral load limit	SORT, 6 DOF	Alters performance by forcing trajectory changes

shown in Table 3.

Table 3 - IDOS Test Scenarios for Vehicle Configuration Design Changes

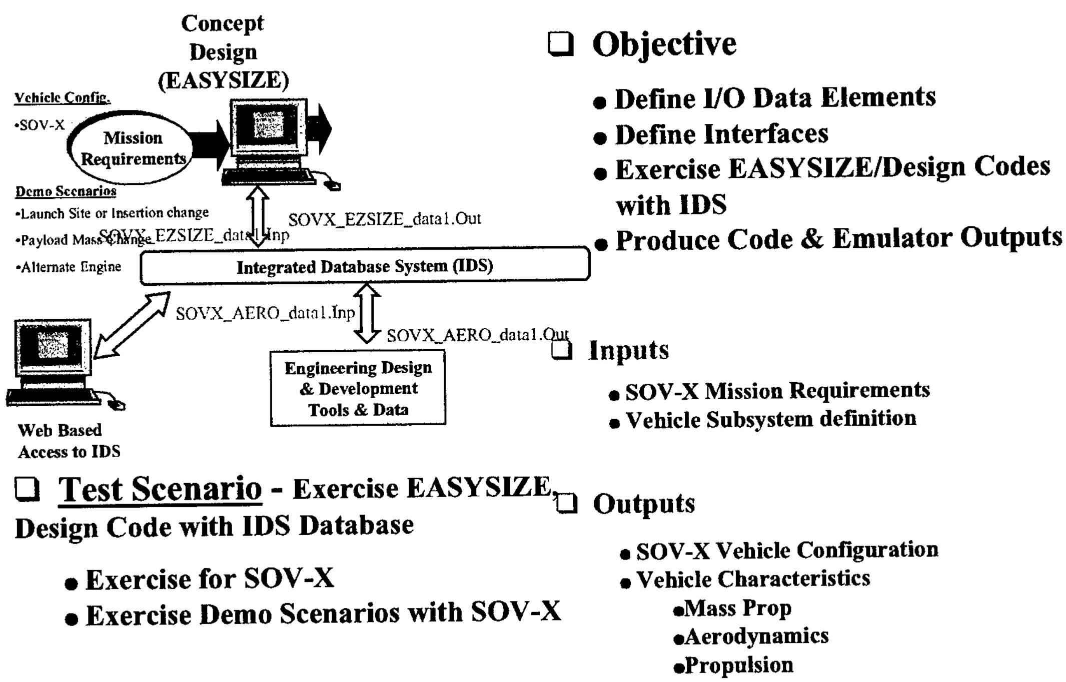
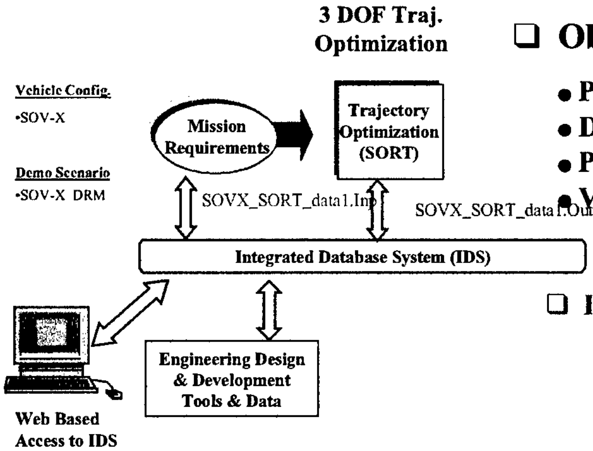


Figure 4 - Element Test E-6 Verifies EASYSIZE and Design Code Operation with IDS

Each of the 47 tests outlined in Table 2 had a specific test objective, test configuration and inputs and outputs defined. Examples of these incremental tests are shown in Figures

4 – 7 for the EASYSIZE, 3 DOF simulation, MatrixX 6 DOF simulation, and with the end-to-end IDOS system test.



❑ Objective

- **Provide SORT truth model via IDS**
- **Define SORT/IDS I/O and Interfaces**
- **Produce SORT Outputs for validation**
- **Validate SORT and IDS operation**

❑ Inputs

- **SOV-X Mission Requirements**
- **SOV-X Vehicle Configuration**
- **Vehicle Characteristics**
  - **Mass Prop**
  - **Aerodynamics**
  - **Propulsion**

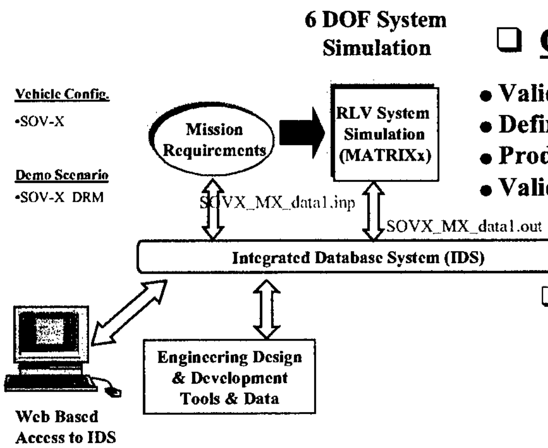
❑ Outputs

- **Trajectory & Vehicle Environment**
- **Guidance Commands & Sequencing**

❑ <u>Test Scenario</u> - Exercise SORT with IDS Database via Web

- **Exercise for SOV-X config.**

Figure 5 - Element Test S-3 Verifies SORT Simulation Interface with IDS



❑ <u>Objective</u>

- **Validate MATRIXx 6 DOF via IDS**
- **Define MATRIXx 6 DOF/IDS I/O and Interfaces**
- **Produce MATRIXx 6 DOF Outputs for validation**
- **Validate MATRIXx 6 DOF and IDS operation**

❑ Inputs

- **SOV-X Mission Requirements**
- **SOV-X Vehicle Configuration**
- **Vehicle Characteristics**
- **Mass Prop**
- **Aerodynamics**
- **Propulsion**
- **Sensors, Effectors & Actuation**
- **GN&C algorithms & Mission Constants**

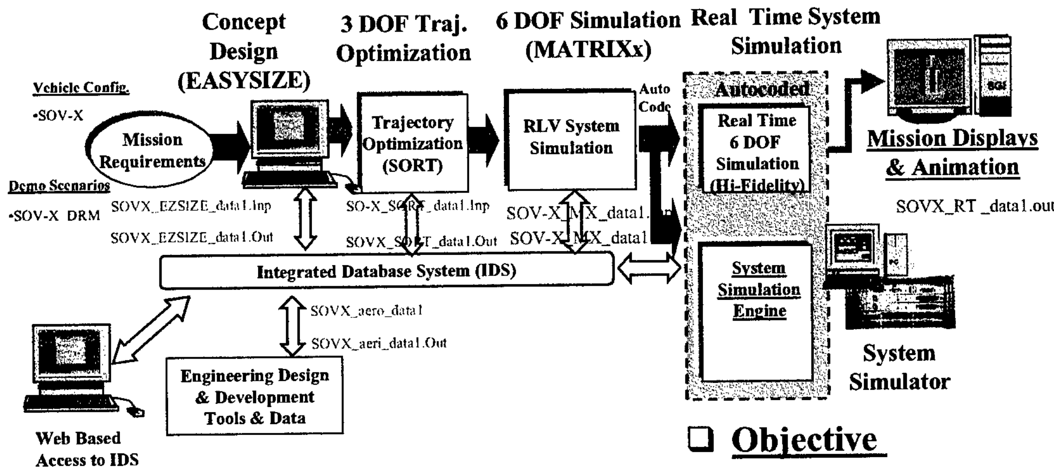
❑ Outputs

- **6 DOF Trajectory & environment**
- **GN&C parameters**

❑ <u>Test Scenario</u> - Exercise MATRIXx 6 DOF with IDS via Web

- **Exercise for SOV-X config.**

Figure 6 - Element Test M-3 Verifies MatrixX 6 DOF Simulation Interface with IDS



❑ **Objective**

- **Provide RT RLV System Sim using IDS via Web interface**
- **Define I/O and IDS Interfaces**
- **Produce Autocoded MATRIXx 6 DOF Outputs for validation**

❑ **Test Scenario - Exercise End-to-End R&D Simulation using IDS and Web Interface**

- **Exercise for SOV-X config.**
- **Validate with MATRIXx 6 DOF truth model**

Figure 7 - Element Test F-4 Verifies End-to-End RLV Simulation Interface with IDS

IV. Phase I Project Summary

A. End-to-End Simulation Based Toolset Foundation Established

Our end-to-end simulation based R&D toolset involves 11 major elements and process steps (see Figure 8). The elements and associated process steps include: (0) an IDS as the core element used to manage all data consistently throughout the process (1) Mission Requirements definition, (2)Vehicle Sizing, (3) Engineering Design Codes which provide detailed system characteristics data used to populate IDS, (4) 3 DOF simulations with Trajectory Optimization (3 Options were interfaced to IDS in Phase I including, SORT, GVTROP, OTIS), (5) 6 DOF MATRIX Simulation (which represents the analytical "Truth Model"), (6) Autocoding of the 6 DOF for other target processors, (7) Real Time PILS simulation, (8) Monte-Carlo 6 DOF analysis, (9) Real Time Data Processing & Flight Assessment, (10) Supporting Displays & Visualization for steps 0 through 9. Phase I efforts have resulted in the implementation and demonstration of elements supporting steps 0 through 6.

B. Phase I Tasks Completed

All proposed tasked defined in our detailed Statement of Work for Phase I have been completed. A kickoff meeting was held with AFRL at WPAFB at the beginning of the

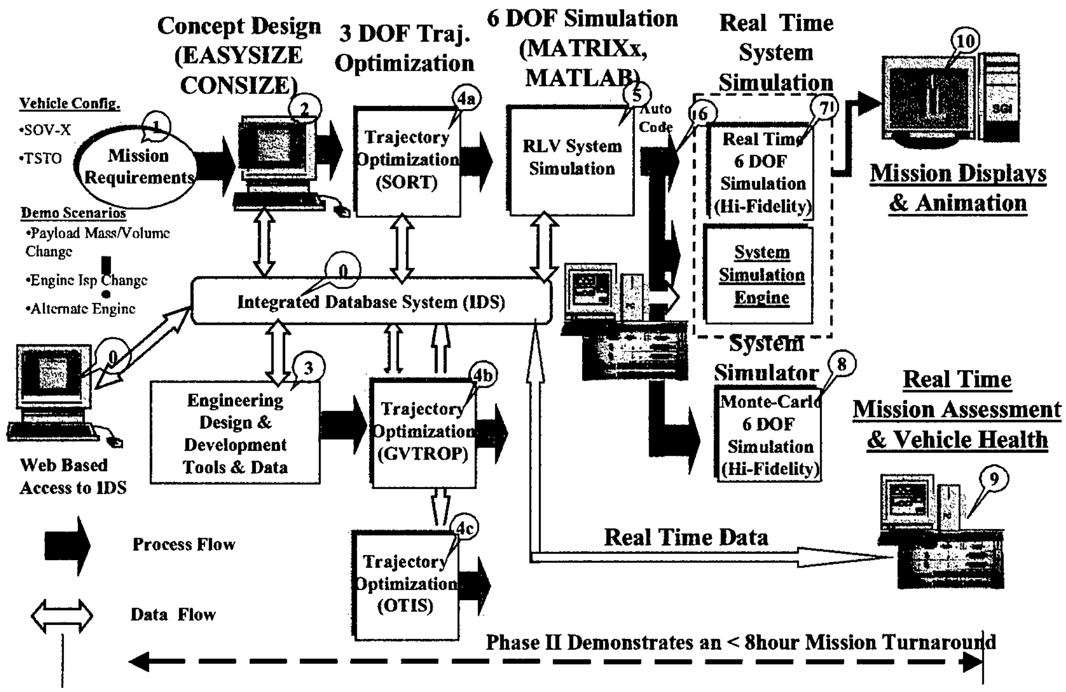


Figure 8 – End-to-end system design process using our Integrated Develop and Operations System (IDOS)

project to confirm that project approach, requirements and expectations for Phase I were understood by all participants. From those initial discussions the architecture, process and tools to be used and integrated with our integrated database system were identified and baselined. A generic version of our Space Clipper SSTO vehicle (designated SOV-X) was chosen as a validation system to verify analytical tool data interfaces to the IDS. Modifications were made to some of these tools in order to support system analysis and IDS interface verification. Specifically EasySize, our concept definition/system performance tool was modified to support RLV studies. GVTROP, one of our 3-DOF performance/trajectory tools was also modified to support launch system design, through the incorporation of Euler-angles to the vehicle position algorithms. EasySize, the 3-DOF trajectory tools (SORT, GVTROP and OTIS), and our MatrixX 6DOF were then interfaced to the IDS through PHP scripting to consistently manage input and output data between these tools and the core database implemented with MySQL on our Pc-based Linux data server. Web-browser interfaces were developed to support interaction with the IDS, and a graphical data analysis application was integrated into the IDS to support evaluation of various analytical tools, and their results. An on-site demonstration and final briefing was provided to the customer at AFRL/WPAFB on 11/3/00 as a final verification and feasibility demonstration of this toolset and design approach.

C. Relevance of Phase I Effort

Our Phase I effort and proposed Phase II work plan has direct relevance to AFRL/WPAFB and in particular work being pursued under the VA Directorate on Space Operations Vehicles, and future reusable launch systems. From inception, and even going back to our individual members experiences in the development and operations of the Delta Clipper Experimental (DC-X), USL has been forced on space transportation operations. Our experience in mission planning, and data evaluation continues to evolve in support of rapid turnaround requirements for future launch systems.

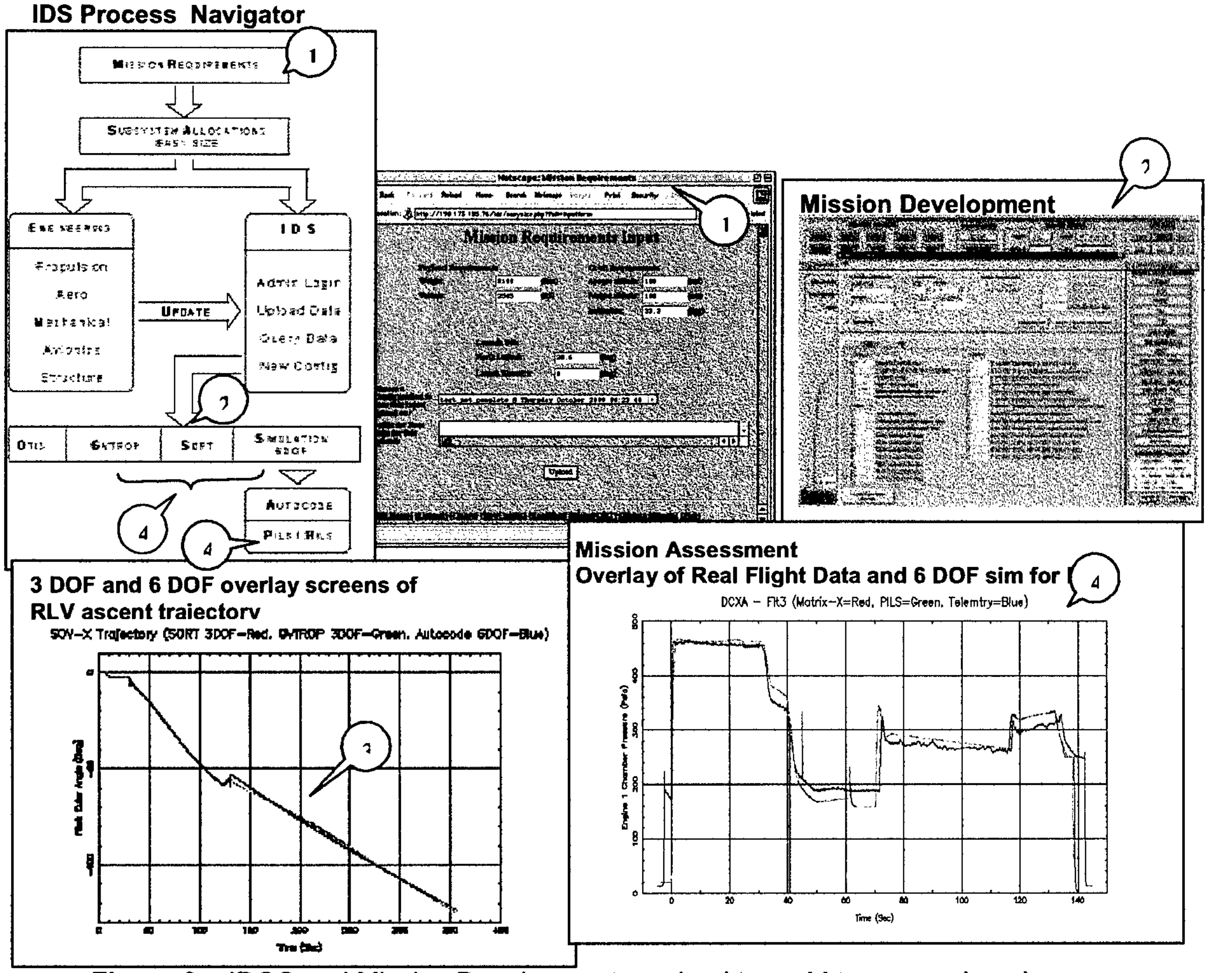


Figure 9 – IDOS and Mission Development can lead to rapid turnaround goals

Specifically we have been evolving ascent trajectory and guidance schemes for RLV's similar to those included in our Phase I IDS development and demonstration effort, which couple with a low cost mission development system prototype developed under NASA NRA 8-15, Bantam Operations Technology activities. Our mission development system prototype demonstrated how a single designer can rapidly define a mission, evaluate the performance and performance sensitivities to key design parameters, validate

performance, evaluate excursions & anomalies, generate flight software and Mission Constants, execute a mission including day/hour of launch decision making and launch, evaluate flight data in real time, and finally assess post- mission performance, overall health and readiness for next flight. To illustrate this process an abbreviated example using the Phase I IDS Navigator is presented in Figure 9. Some selected process steps are shown using the IDS Navigator master screen as shown below. For example (1) Define mission requirements, (2) Develop the mission performance using the SORT 3 DOF, (3) Evaluate and validate performance using 3 DOF and 6 DOF simulations(overlay plot comparisons), (4) Assess real time flight data by overlaying flight and truth model results. The user interfaces are designed for "simplicity" providing maximum functionality, while supporting an easy to use, scalable initial user interface. Mission planning details are "embedded" within pull-down menu options available for the more "sophisticated" user.

We believe the goals of achieving rapid turnaround mission planning and system evaluation are addressed by the simulation based tools, IDS and our development process, together making up our IDOS and this mission development system. Our Phase II project and other activities USL is pursuing in this areas can provide AFRL and the VAC Directorate with additional capabilities necessary to achieve flight rates and turnaround requirements for future launch systems currently under study.